Heating of coronal X-ray Bright Points

Biswajit Mondal

NASA Postdoctoral Program

NASA Marshall Space Flight Centre

Huntsville, Alabama, USA

Amy R. Wineberger (NASA Marshall Space Flight Centre),

P.S. Athiray (Univ. of Alamaba in Huntsville,, NASA MSFC)

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About me..

Graduated from Physical Research Laboratory, India, 2022

NPP at NASA Marshall Space Flight Center, USA, 2023

Contact me:
biswajit.mondal@nasa.gov

Group and collaborators

MSFC heliophysics team:

Dr. Amy R. Wineberger,

Dr. P.S. Athiray,

Dr. Sabrina L. Savage
and MaGIXS team.

Collaborators:

Dr. Helen E. Mason (Univ. Cambridge)

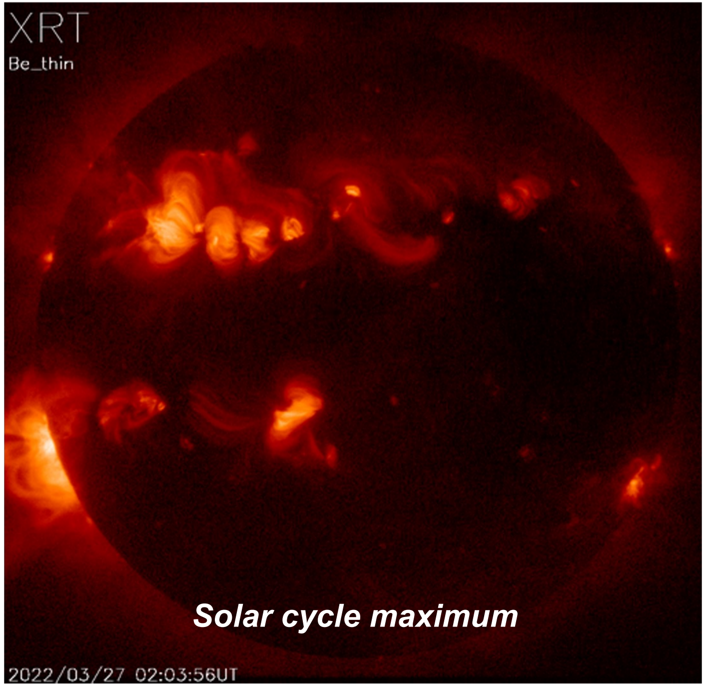
Dr. Giulio Del Zanna (Univ. Cambridge)

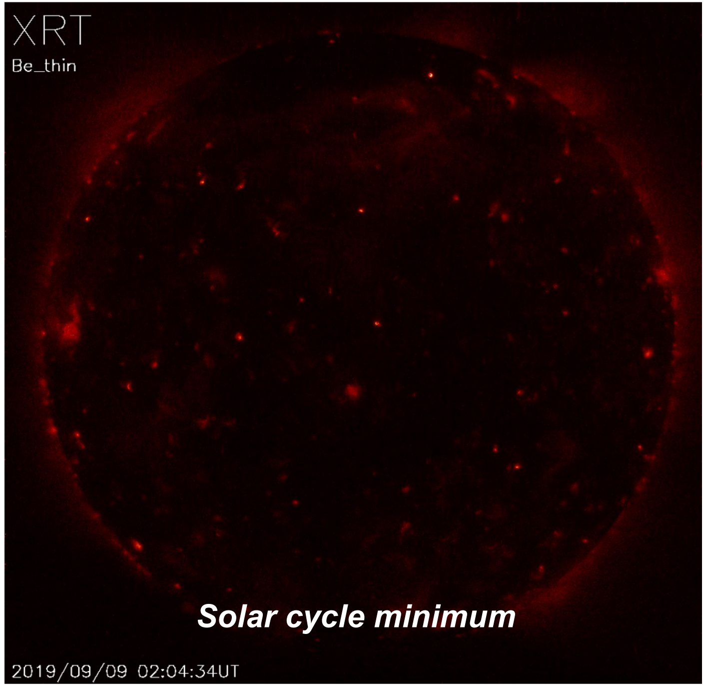
Dr. J.A. Klimchuk (NASA GSFC)

Dr. Aveek Sarker (PRL)

Dr. Santosh Vadawale (PRL) and others!

What are the XBPs?



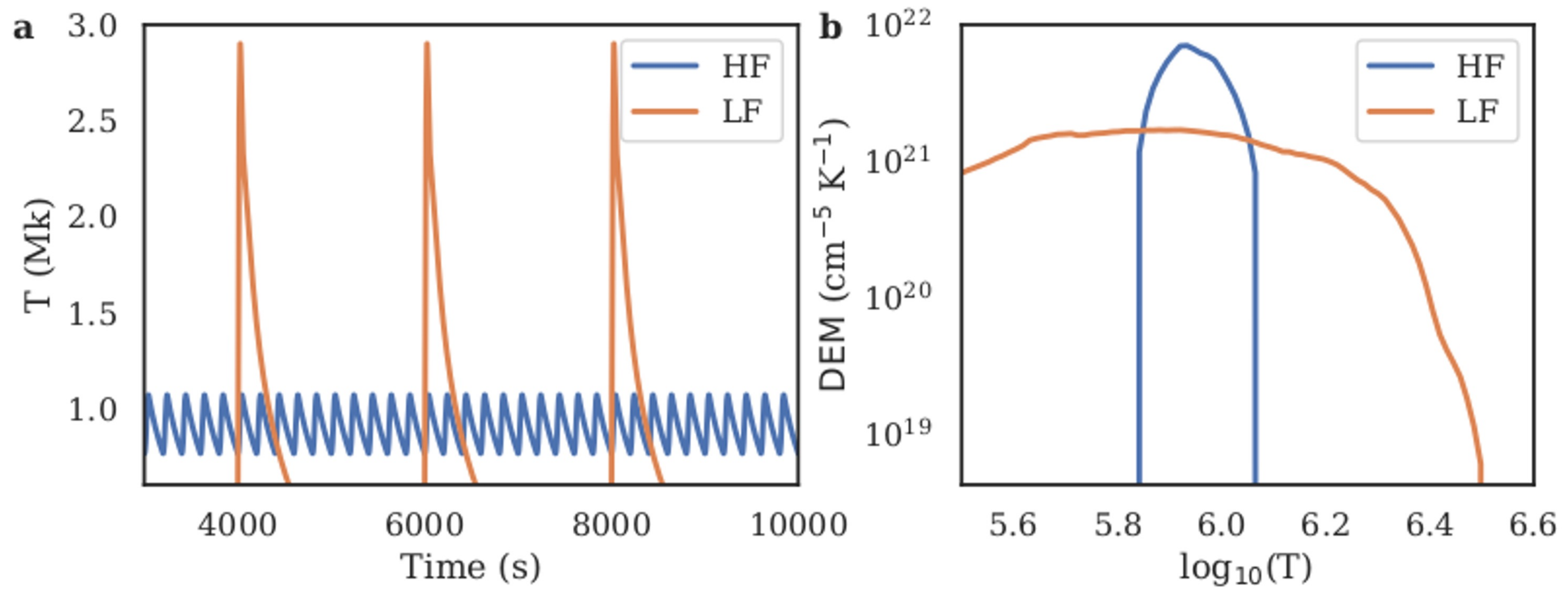


- ➢ XBPs are located all over the solar disk. (Vaiana et al., 1973; Krieger et al., 1971; Golub et al., 1974)
- ➢ In the solar maxima, their contribution is hidden behind the huge AR emission.
- ➢ During the quiet phase XBPs are the primary on-disk X-ray contributors.

Questions

- Fraction of the total quiet Sun X-rays contributed by the XBPs
- Can nanoflare maintained the heating of the XBPs?
- If yes, what is the nanoflare frequency?

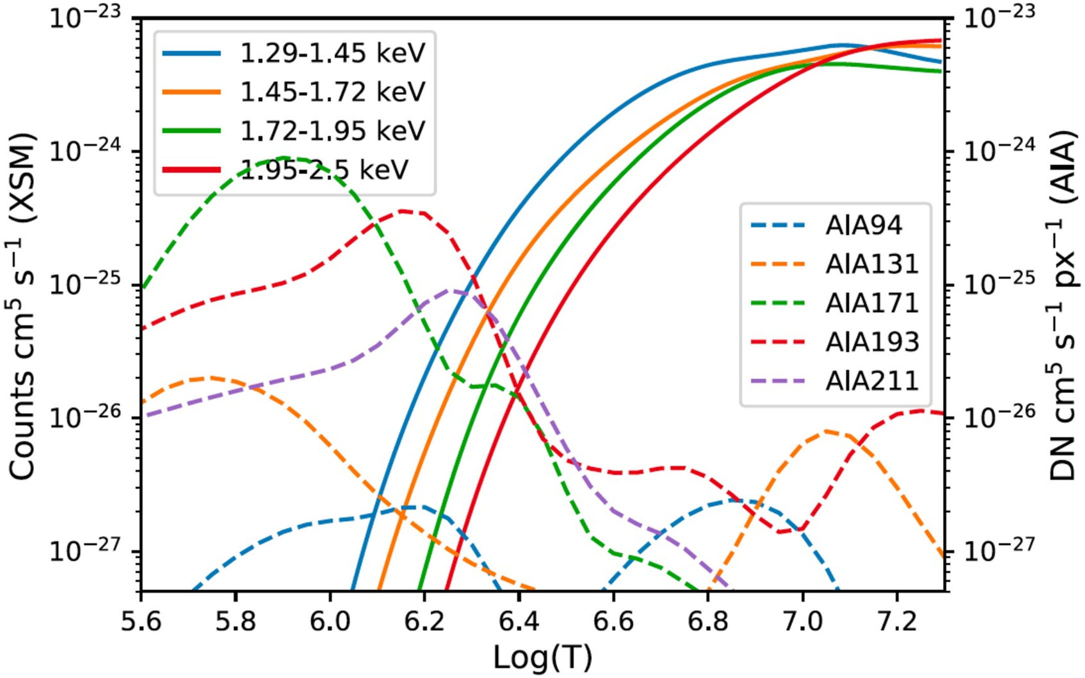
Differential Emission Measure (DEM) -> Diagnostics of Multi-thermal plasma



DEM reconstructions

$$O_i = \int_T DEM(T)\; R_i(T)\; dT \; + \; \delta O_i$$

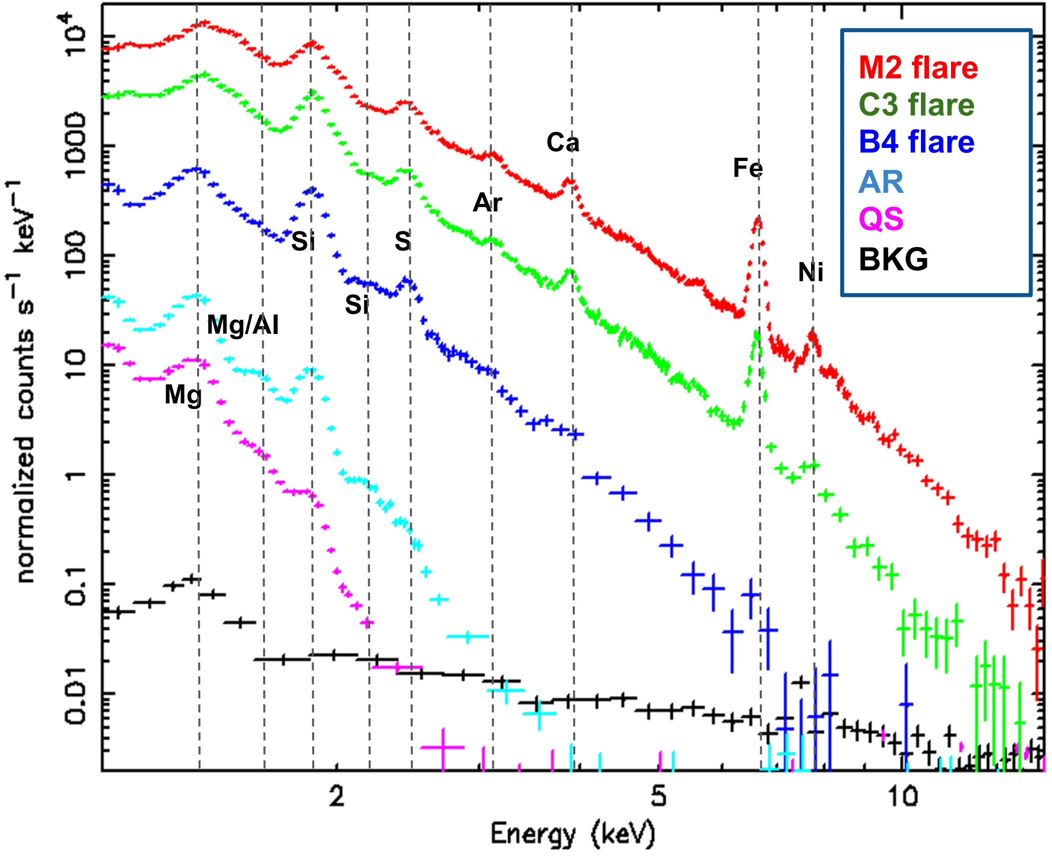
Observed Intensity



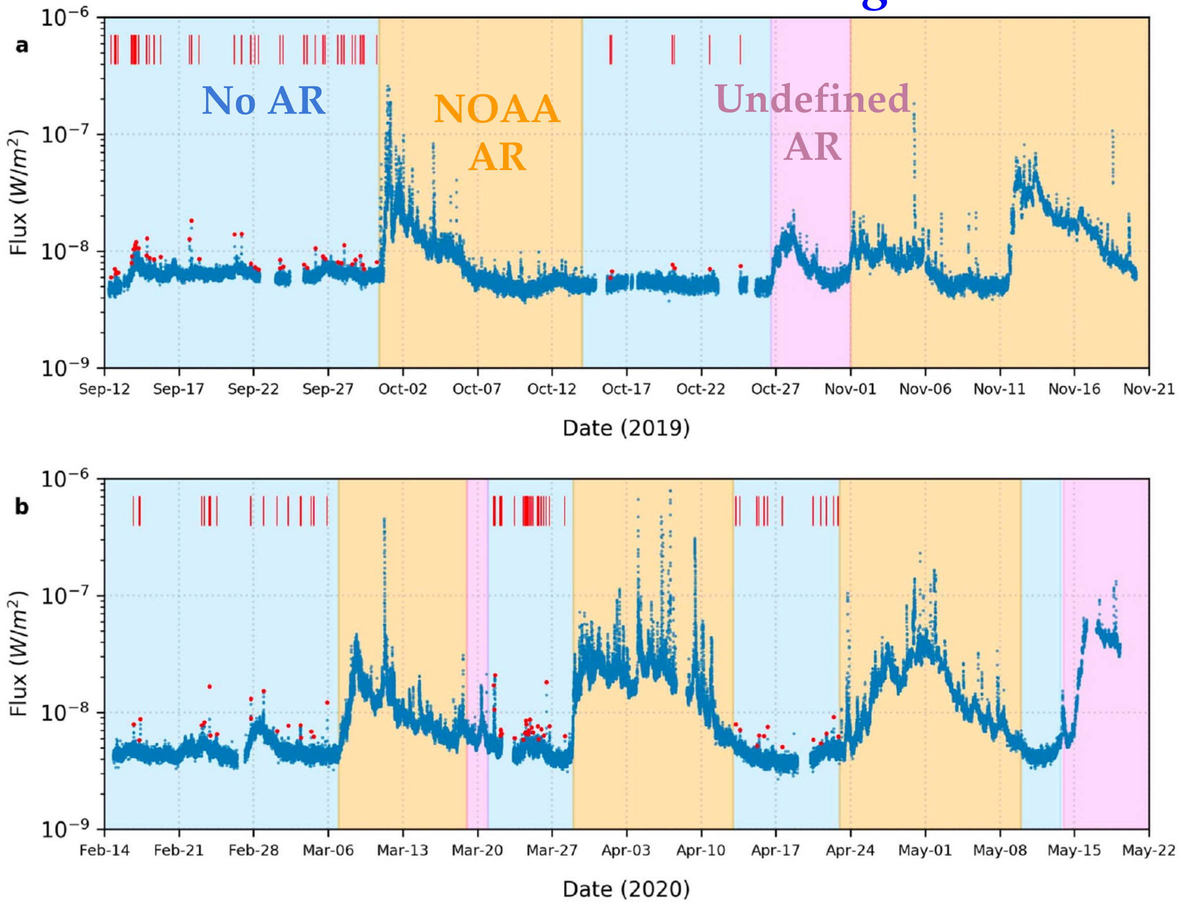
Chandrayaan-2 Solar X-ray Monitor (XSM)

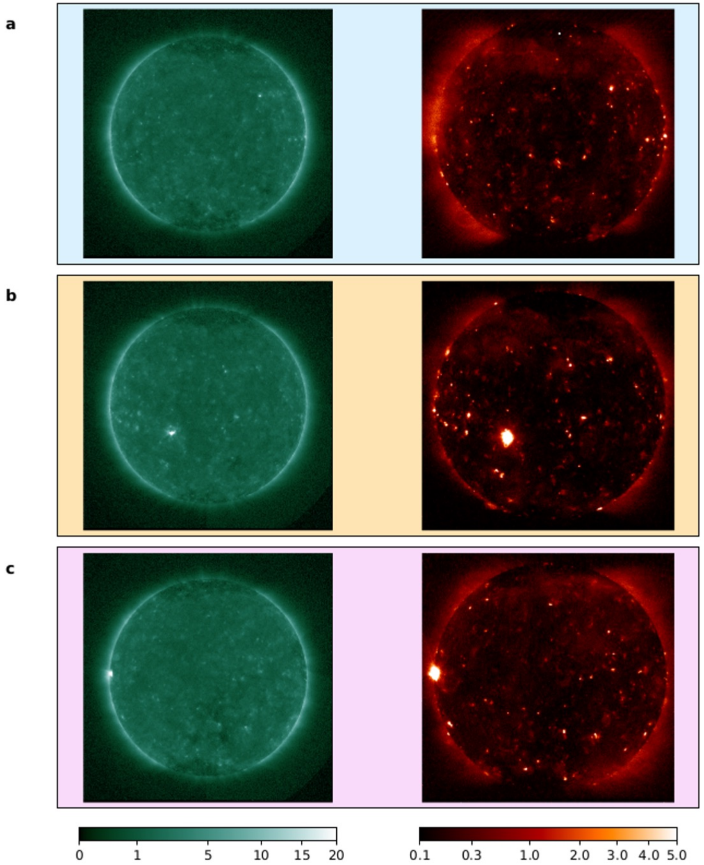
- ➢ Disk-integrated soft X-ray spectrometer of the Sun
- ➢ Energy range: 1-15 keV(< M5 class) or 2-15 keV (> M5).
- ➢ Energy resolution: of 175 eV @ 5.9 keV.
- ➢ Cadence: 1 second
- ➢ Dynamic range: Sub-A to X-9 class flux level

XSM website: https://www.prl.res.in/ch2xsm/



XSM Observations during the minimum of solar cycle 24

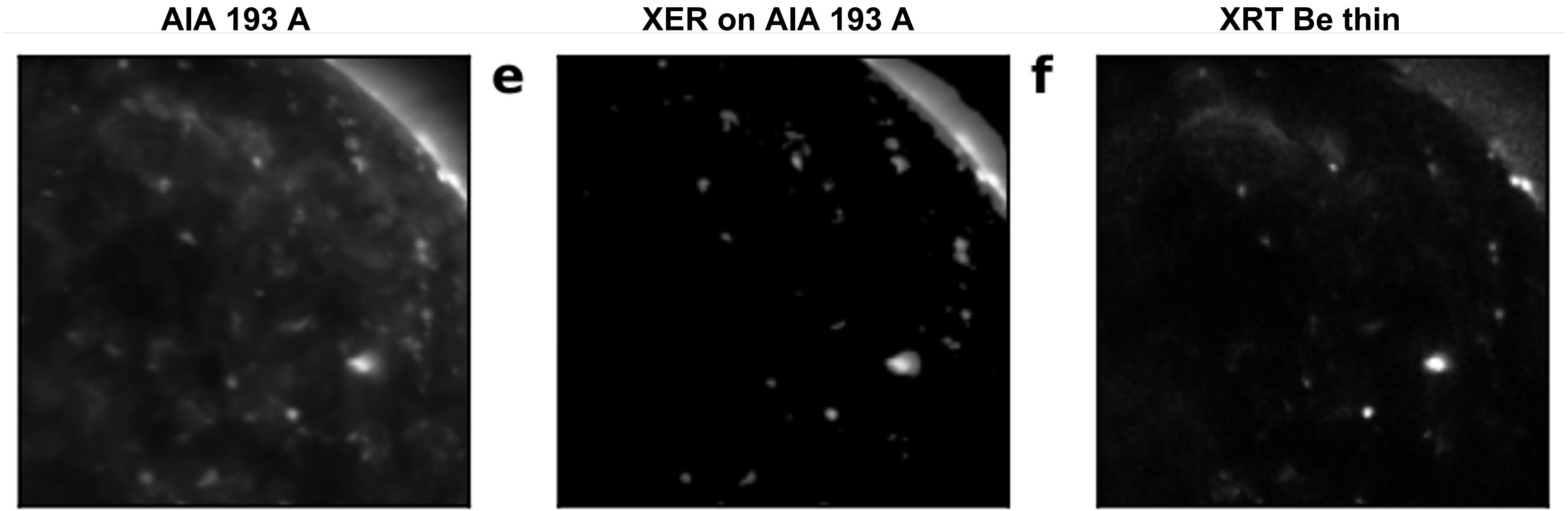




- XSM spectra has the informations of temperature, EM as well as the abundances of Mg, Al, and Si.

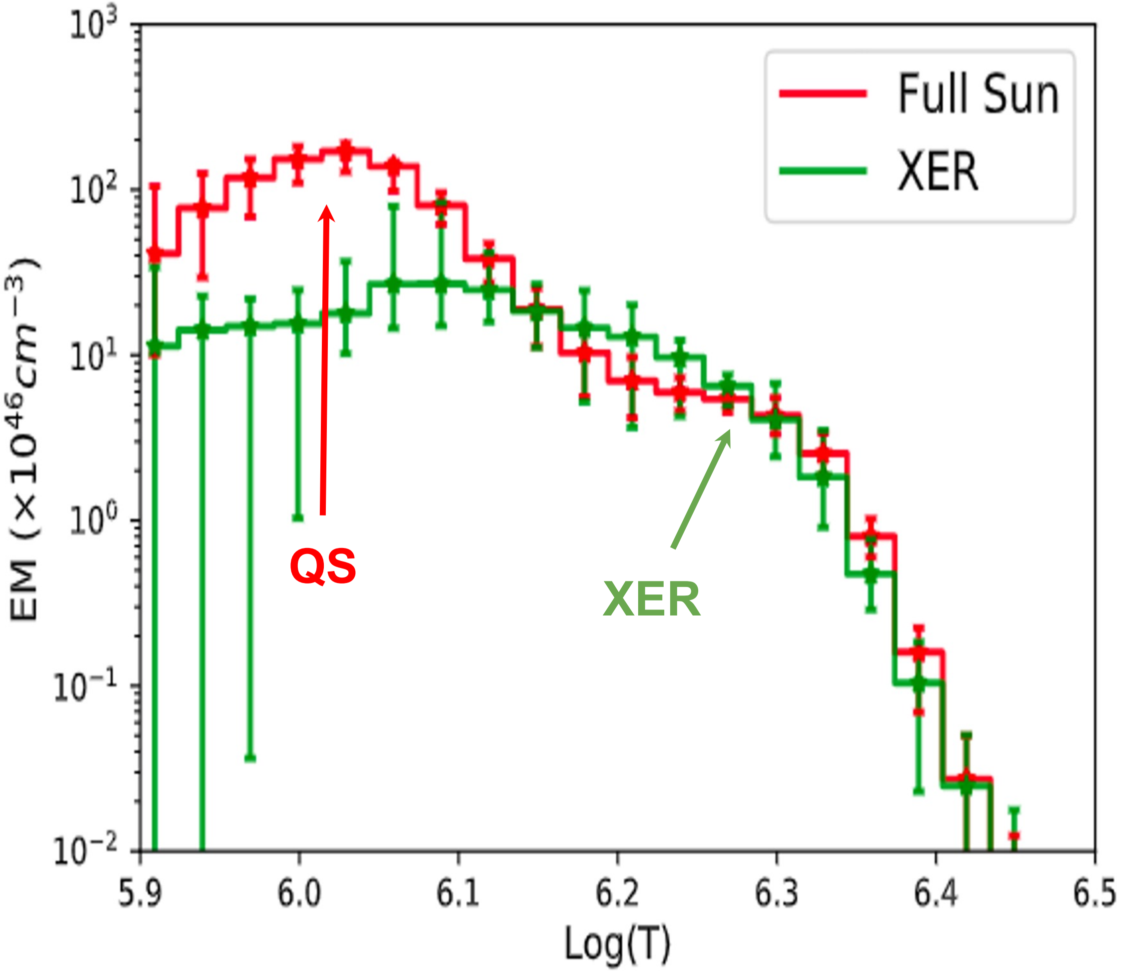
Vadawale, et al, (ApJL 912:L13, 2021 & 912:L12)

Extracting the XER emission from AIA



Mondal et al, (ApJ, 945:37, 2023)

DEM of Full sun & XERs

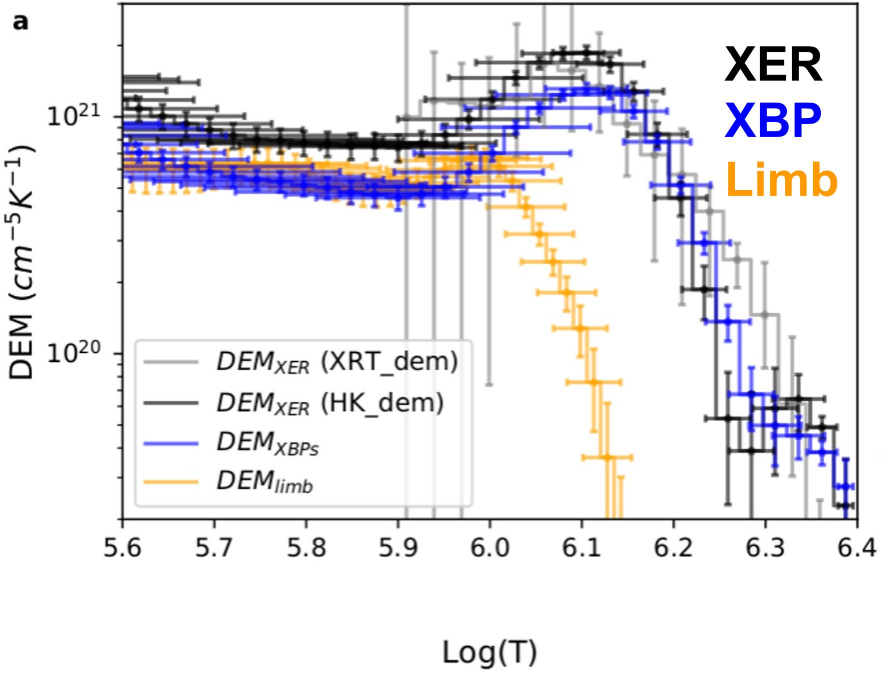


Full Sun -> XER + diffuse corona

XER -> XBPs + limb

Mondal et al, (ApJ, 945:37, 2023)

Separate the different QS component



$$\mathcal{R} = \sum_i EMD(T_i)\ \Lambda(T_i)$$

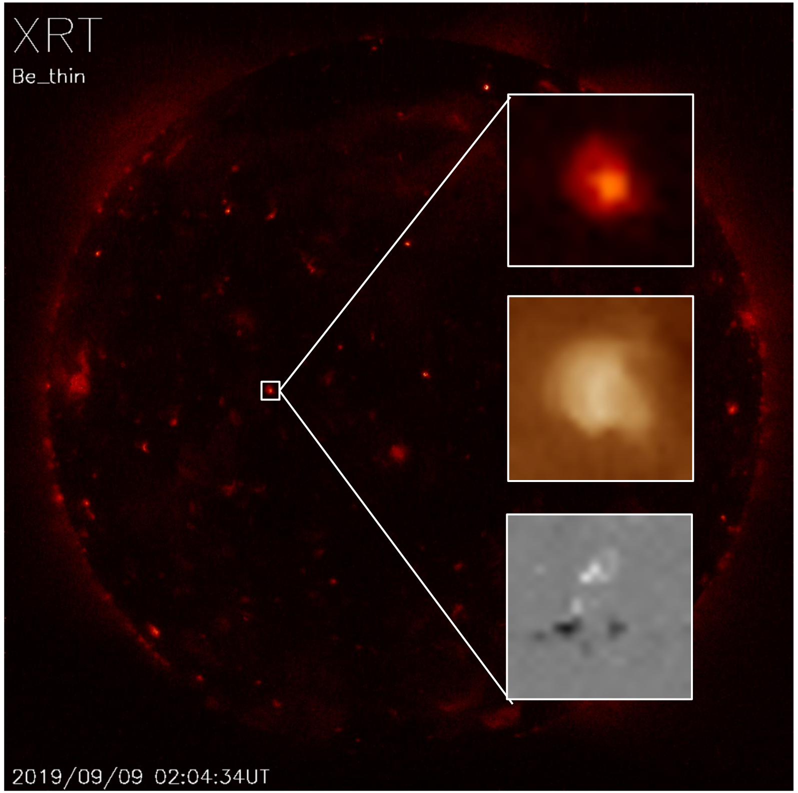
DEM used	$\mathcal{R}(5.6 \leq logT \leq 6.1)$ (erg cm^{-2} s^{-1})	$\mathcal{R}(6.1 \leq logT \leq 6.4)$ (erg cm^{-2} s^{-1})
$DEM_{FullSun}$	0.78×10^5	0.09×10^5
DEM_{XER}	1.69×10^5	1.01×10^5
DEM_{XBPs}	1.08×10^5	0.87×10^5

➢ Lower temperature radiation loss from the diffuse corona is significant whereas at higher temperature it is negligible.

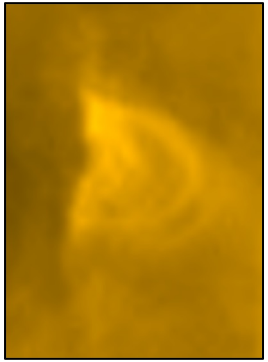
➢ Lower temperature XBPs emission is more than 63%, while at higher temperature it is more than 85%

Mondal et al, (ApJ, 945:37, 2023)

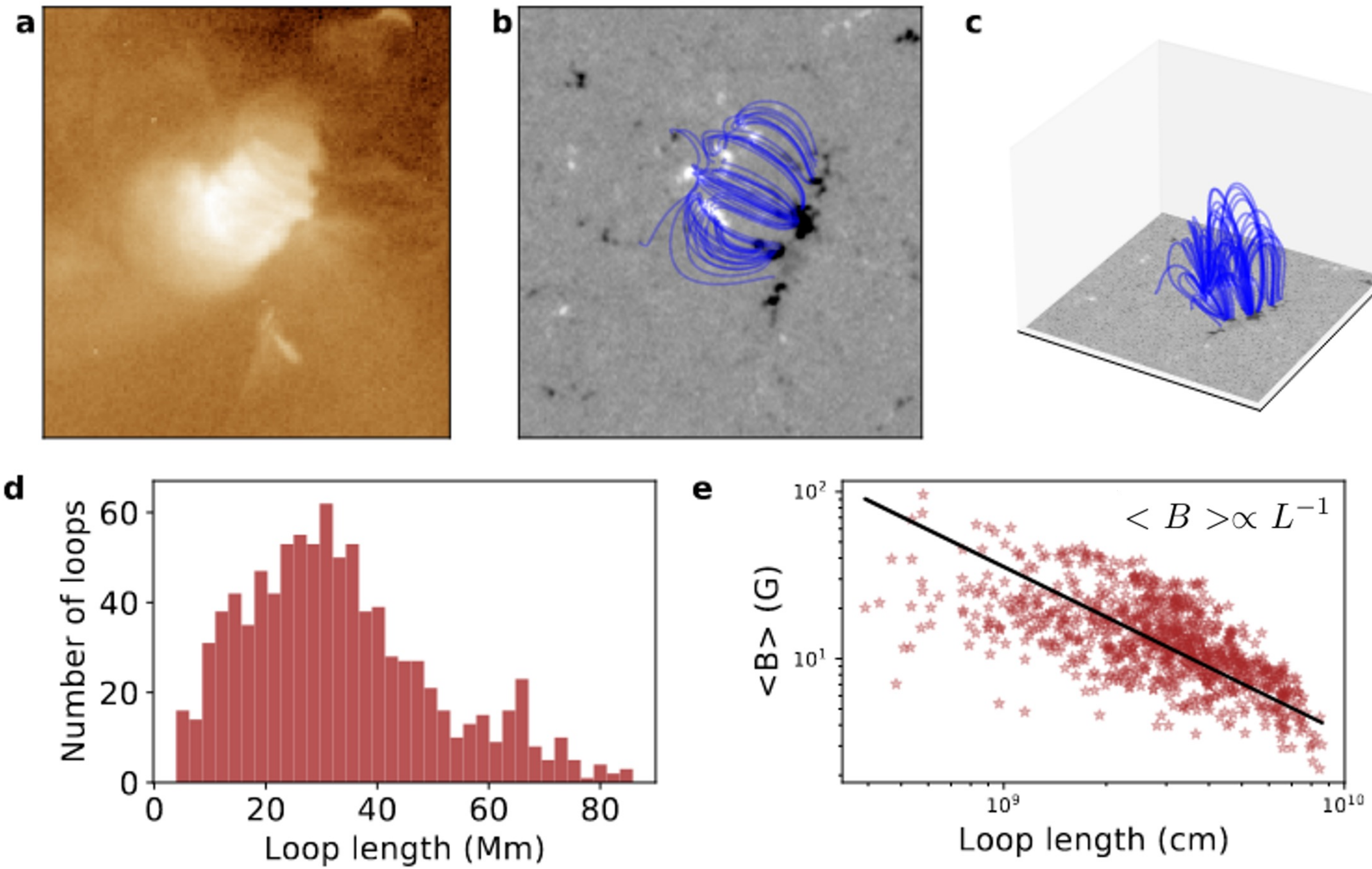
Can nanoflares be responsible to heat the XBPs?

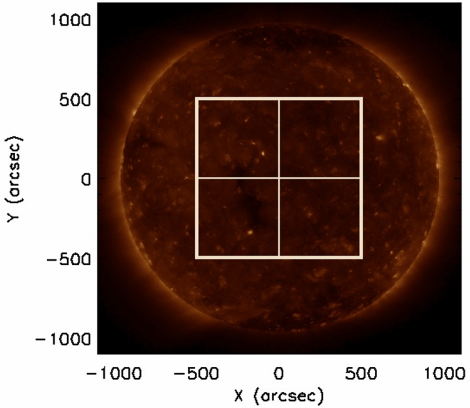


- Modeled the XBP's assuming nanoflare heating scenario.
- Estimate the simulated DEM, which is compared with the observed DEM.
- We used EBTEL code (Klimchuk et al. 2008; Cargill et al. 2012; Barnes et al. 2016).



Magnetic skeleton of XBPs





$$N_i = \frac{A_i}{2\pi r^2}$$

assume, r = 1 Mm

Heating function

- Here we consider that nanoflares occur with the release of stored magnetic energy (Parker, 1988)
- Magnetic stored energy density :

$$E = \frac{(tan(\theta) < B >)^2}{8\pi} (erg\ cm^{-3})$$

- tan(θ) = c –> 0.2 − 0.3, to satisfy observed coronal heating requirement (Parker 1988; Klimchuk 2015).
- Consider triangular heating profiles having a duration (τ) of 100 s.
- The peak heating rate during an event is randomly chosen between minimum (H_0^{min}) and maximum (H_0^{max}) values that are loop dependent.

$$H_{0_{ij}}^{max} = \frac{1}{\tau} \frac{(c < B >_{ij})^2}{8\pi} (erg\ cm^{-3}\ s^{-1})$$

$$H_0^{min} = 0.01\ H_0^{max}$$

$$d_{ij}^l = \frac{\tau L}{F} \times H_{ij}^{l-1}$$

H_0 is randomly chosen between minimum (H_{0ij}^{min}) and maximum (H_{0ij}^{max}) for a loop.

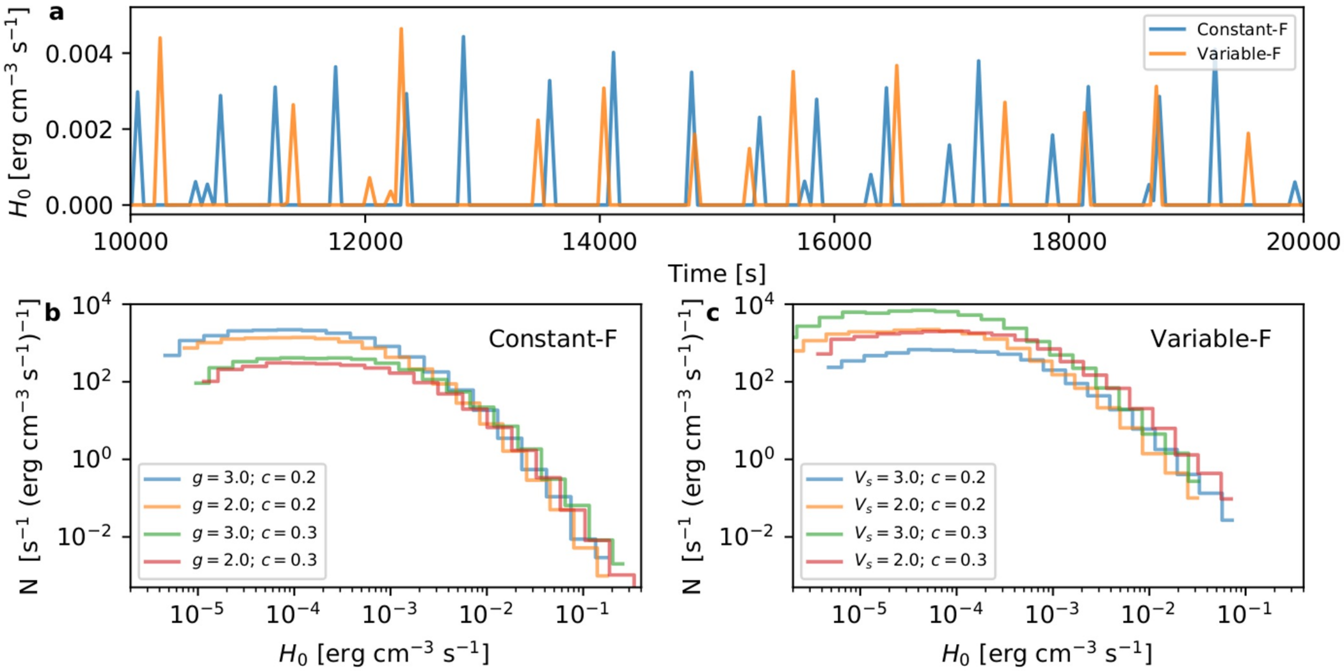
- Model parameters → *c* and *F*

Mondal et al, (ApJ, 945:37, 2023)

Heating function

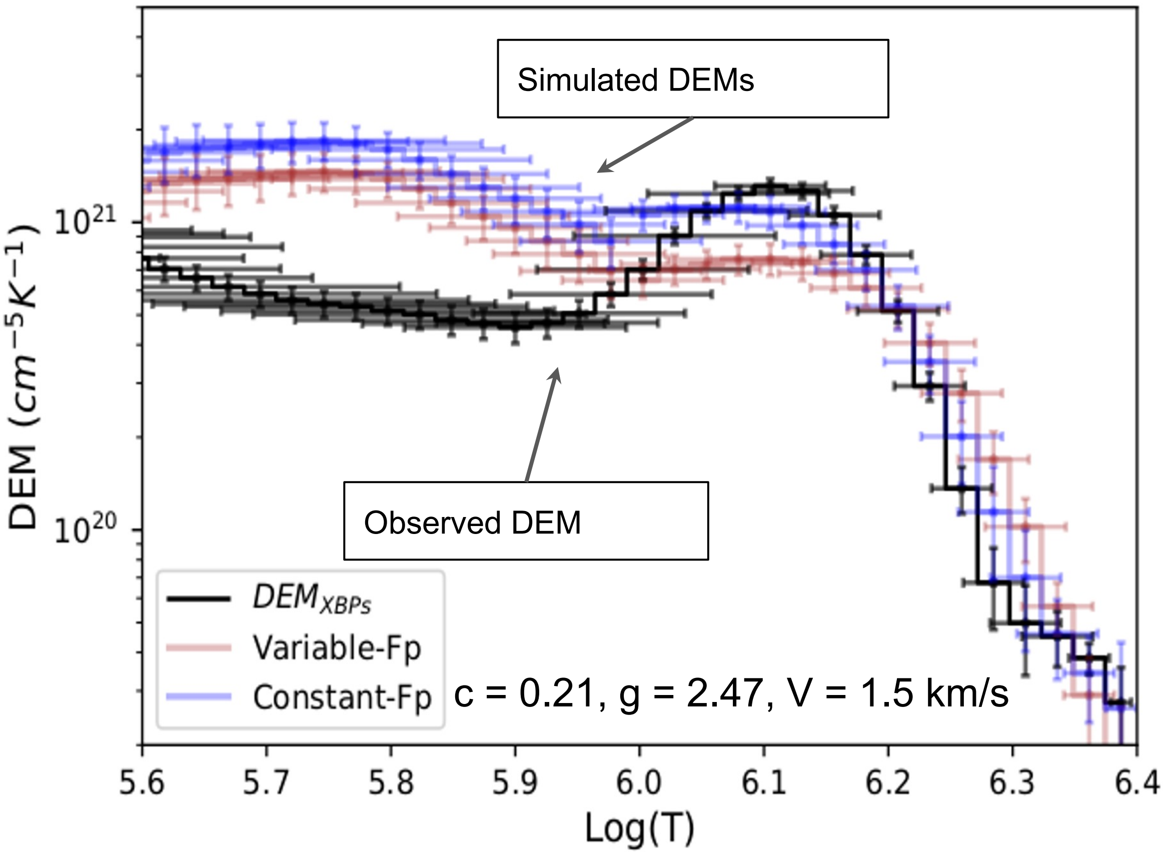
Coronal radiation loss

- Constant *F*: $F = g \times \boxed{1.95 \times 10^5\ (erg\ cm^{-2}\ s^{-1})}$; *g* —> 2 to 3 (Klimchuk et al. 2008)
- Variable *F*: $F_{ij} = -\frac{1}{4\pi} V_h \tan(\theta)\ B_{ij}^{base} < B >_{ij}$; V_h —> 0.5 to 2 km/s



L =30 Mm
< B >=10 G
c = 0.25
g = 2.0
V_h=1 km/s
B_{base} = 15 G

Simulated DEM convolved with instrument responses

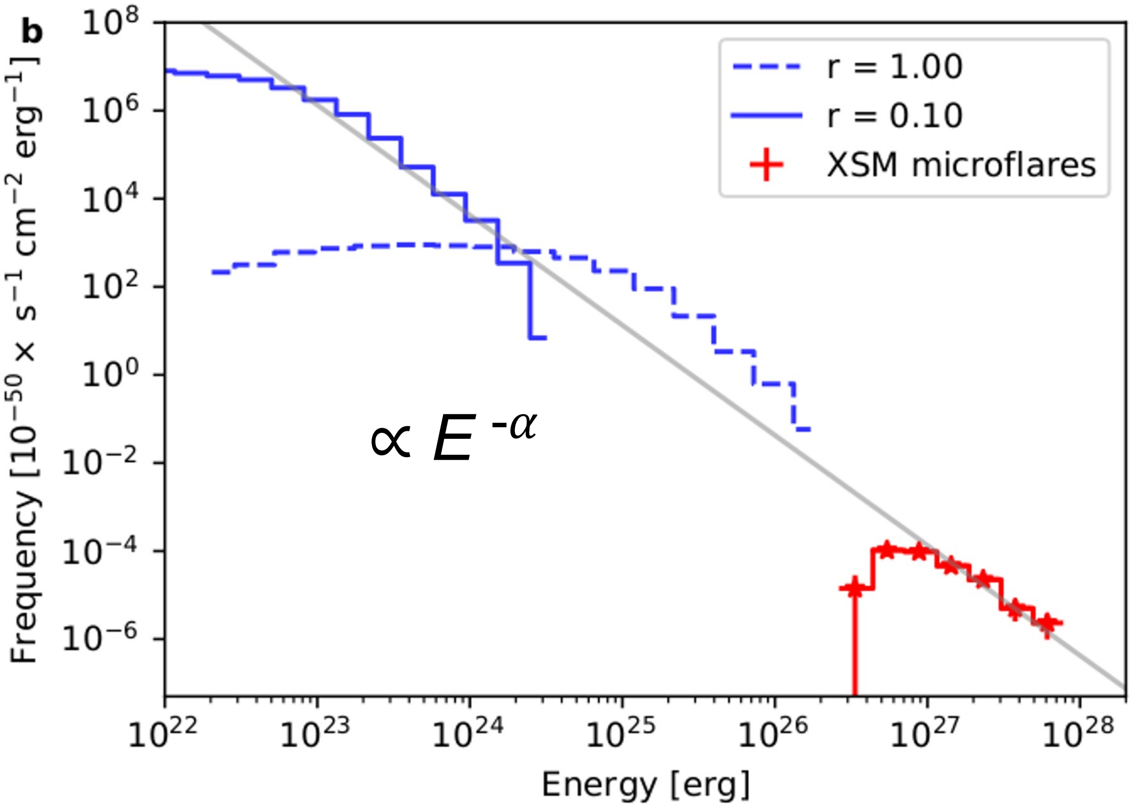


- Still, model DEM predicts 2-3 times higher emission at lower T.
- Simulated TR predicts a larger emission than the observed one —> common (e.g., Warren et al. 2008) in loop simulations.
- Possibility – absorption TR emission by frequent chromospheric jets, such as spicules (De Pontieu et al. 2009)

➢ Agreement for the coronal portion of the loops suggest nanoflare can maintain the heating of XBPs.

Mondal et al, (ApJ, 945:37, 2023)

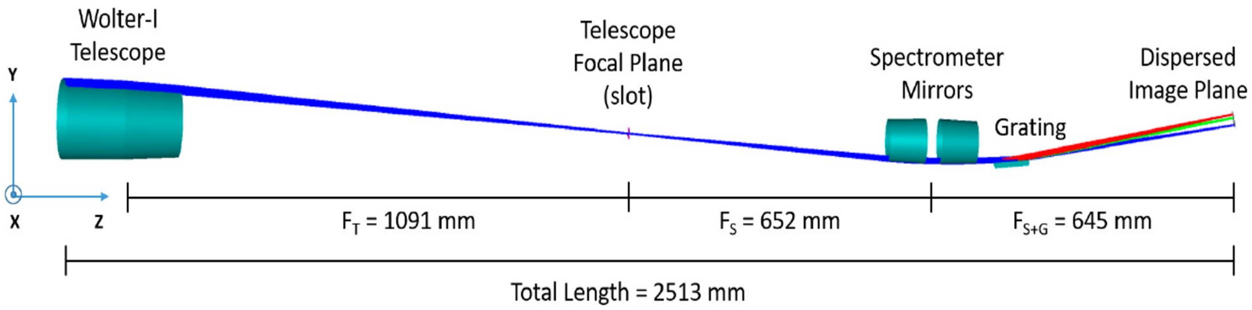
Frequency distribution with nanoflare energy



- Power-law slope -2.5 : Nanoflares energy > larger flares or microflares.

Detailed study for a single XBP

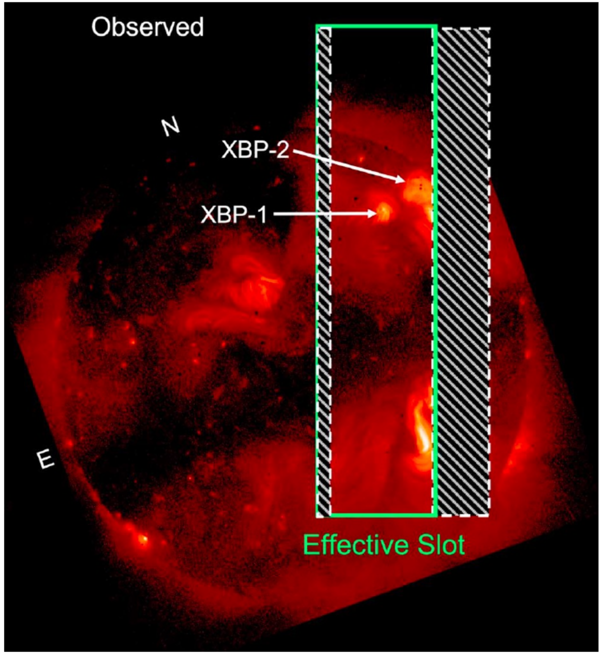
Marshall Grazing Incident X-ray Spectrometer (MaGIXS)

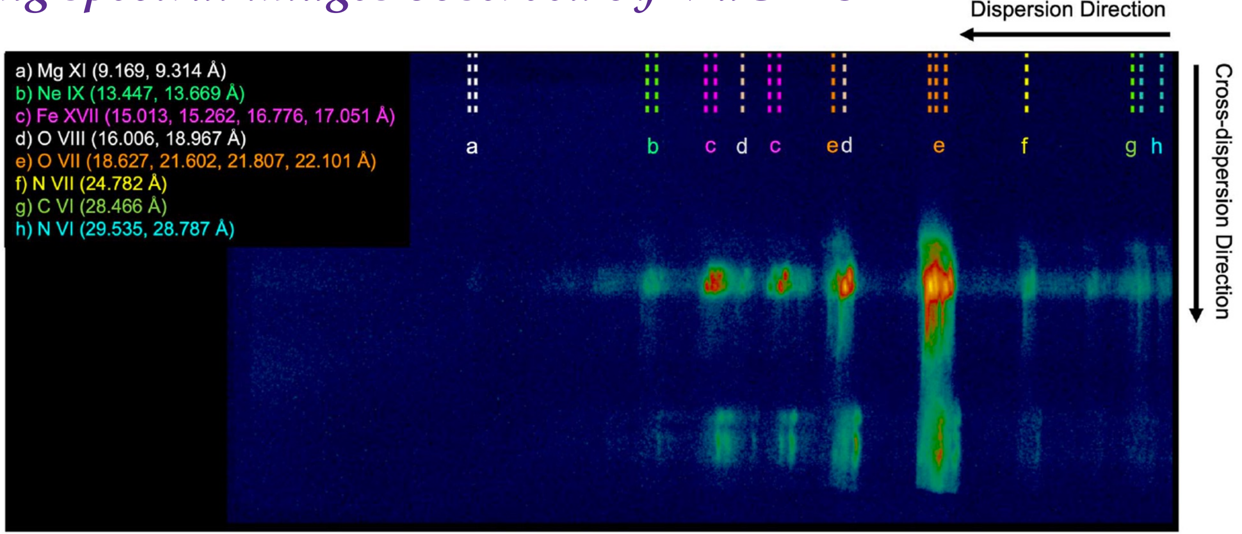


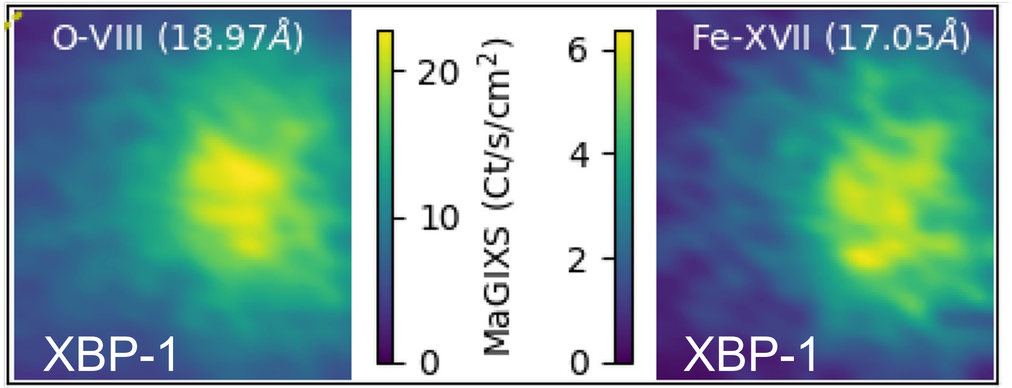
Champey et al. 2022

July-30-2021, 18:20 UT

Overlapping spectral images observed by MaGIXS

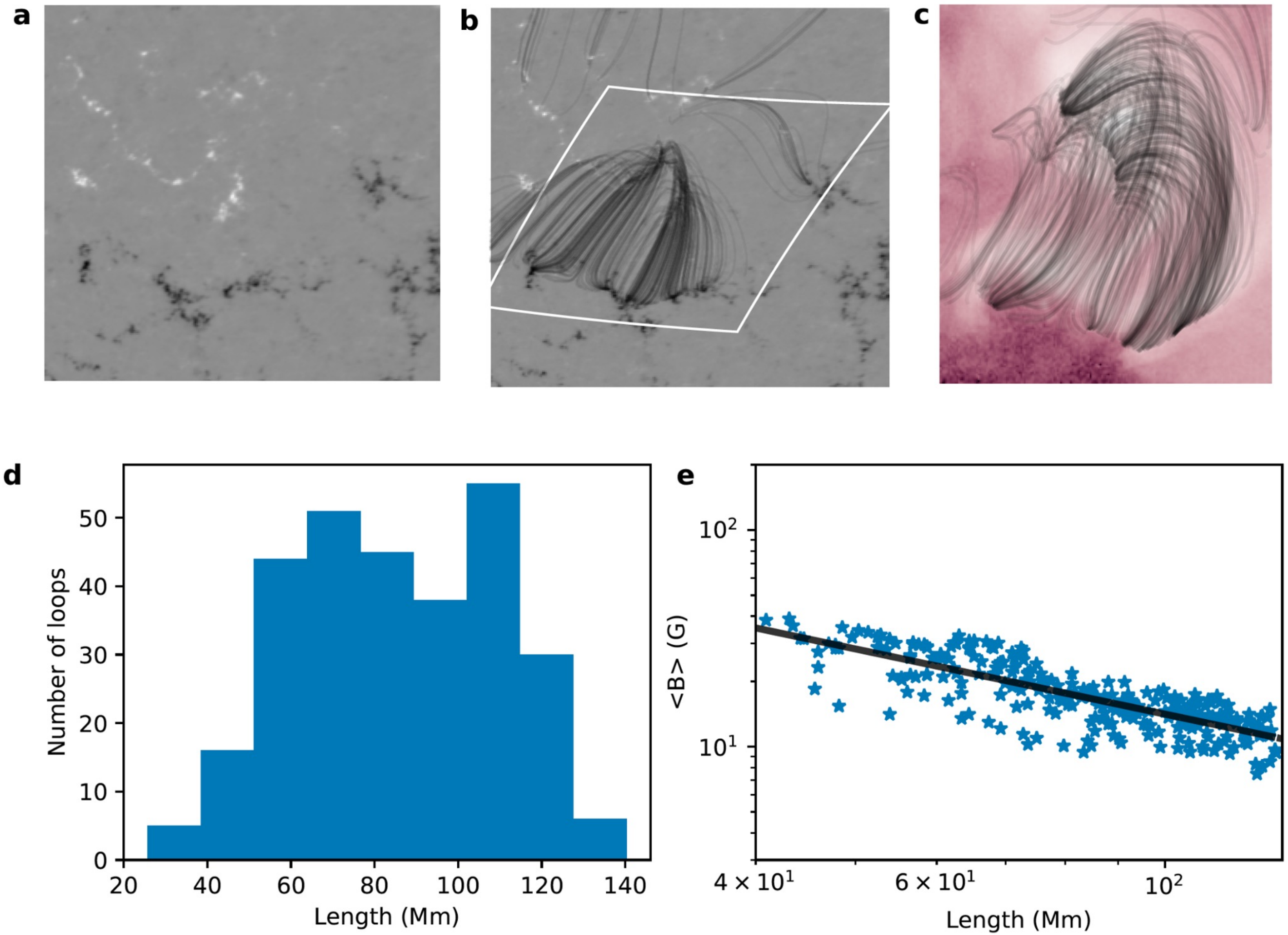






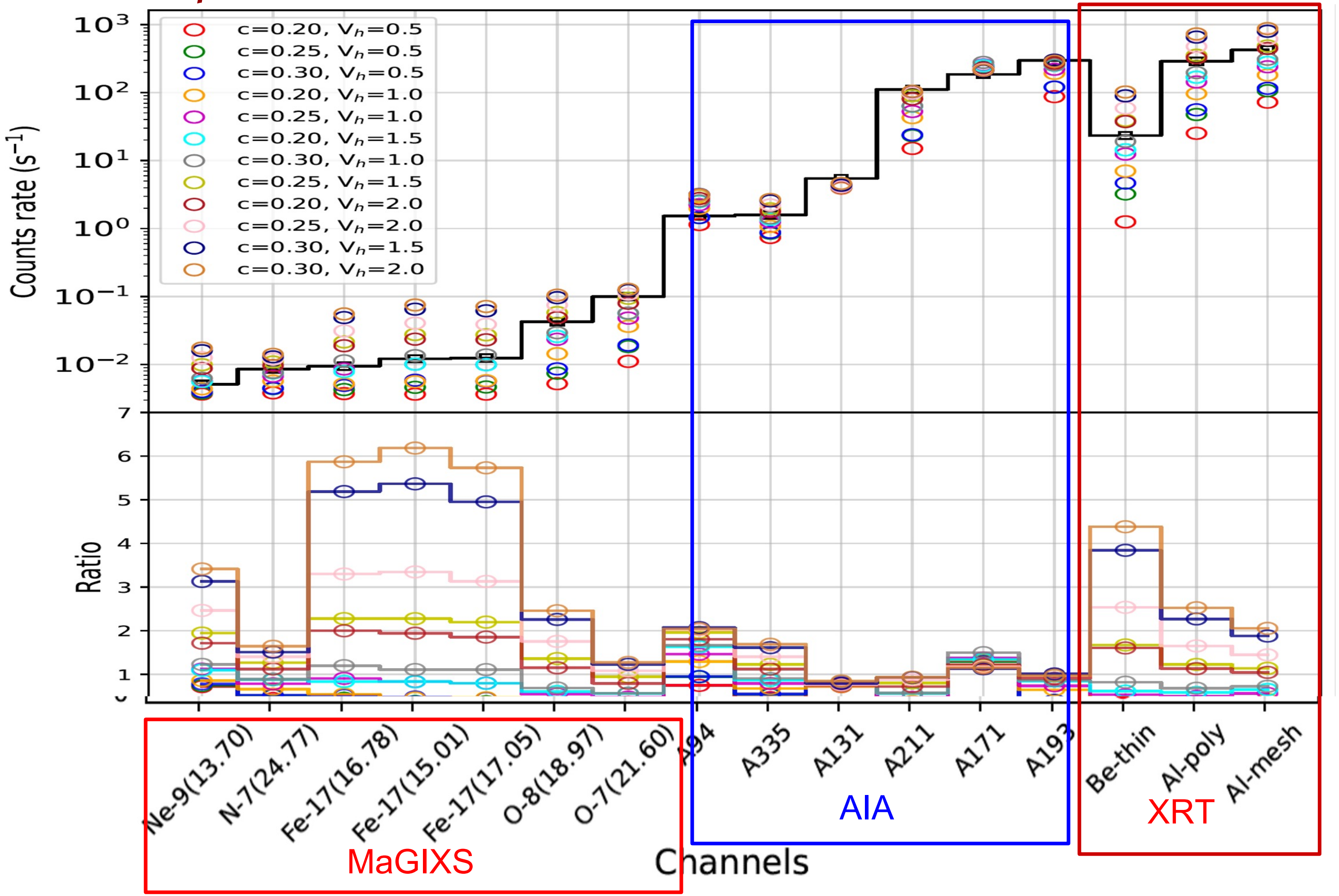
Savage et al (ApJ 945:105, 2023)

Hydrodynamic simulation of XBP-1

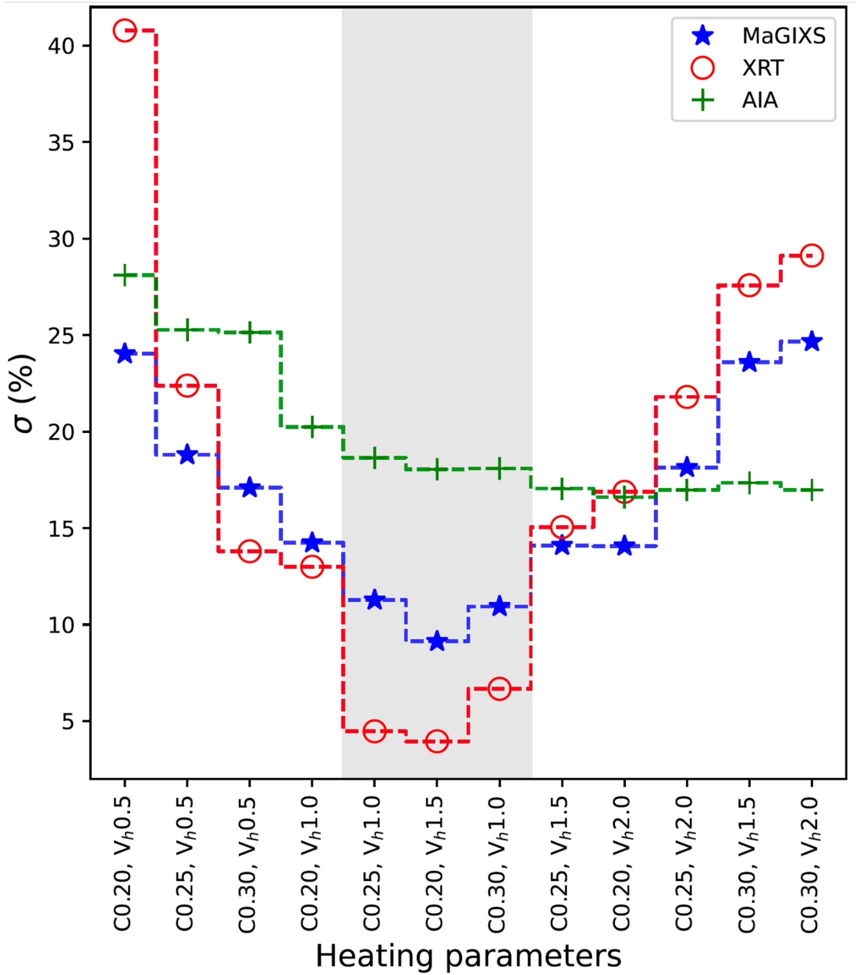


Used 1D hydrodynamic code, HYDRAD

Comparison between simulations and observations



Results & Discussions



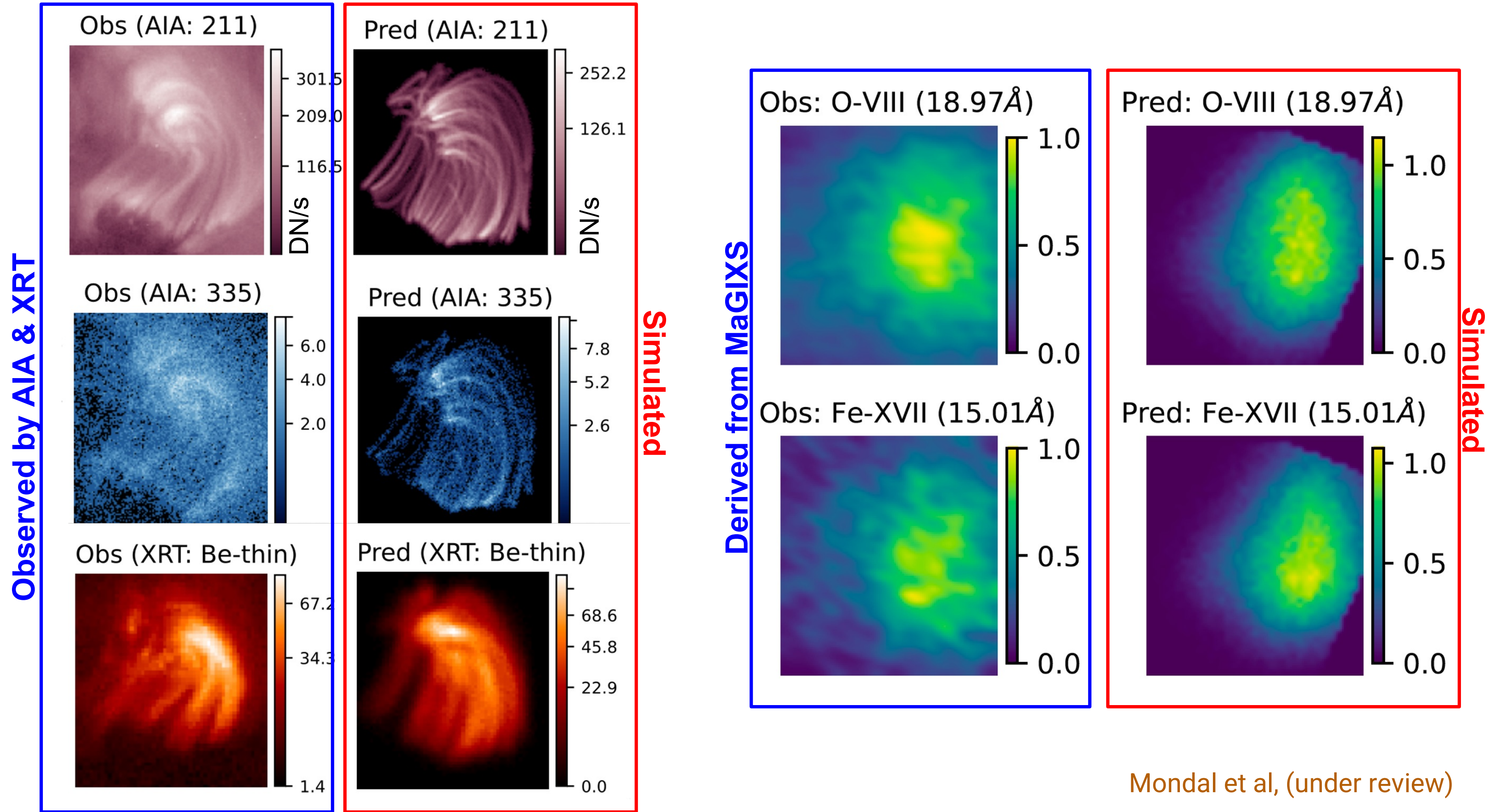
➢ HF nanoflare -> average delay = 1500 - 3000 s (Which is smaller than the cooling time of the loops derived from the formula by Cargill et al 2014).

➢ Average Poynting flux = ~5e5 erg/cm2/s

➢ MaGIXS and XRT are more sensitive.

Mondal et al, (under review)

Observed and Predicted images of XBP-1



Mondal et al, (under review)

Summary

- Most of the high temperature emissions of the Sun in the absence of ARs comes from XBPs

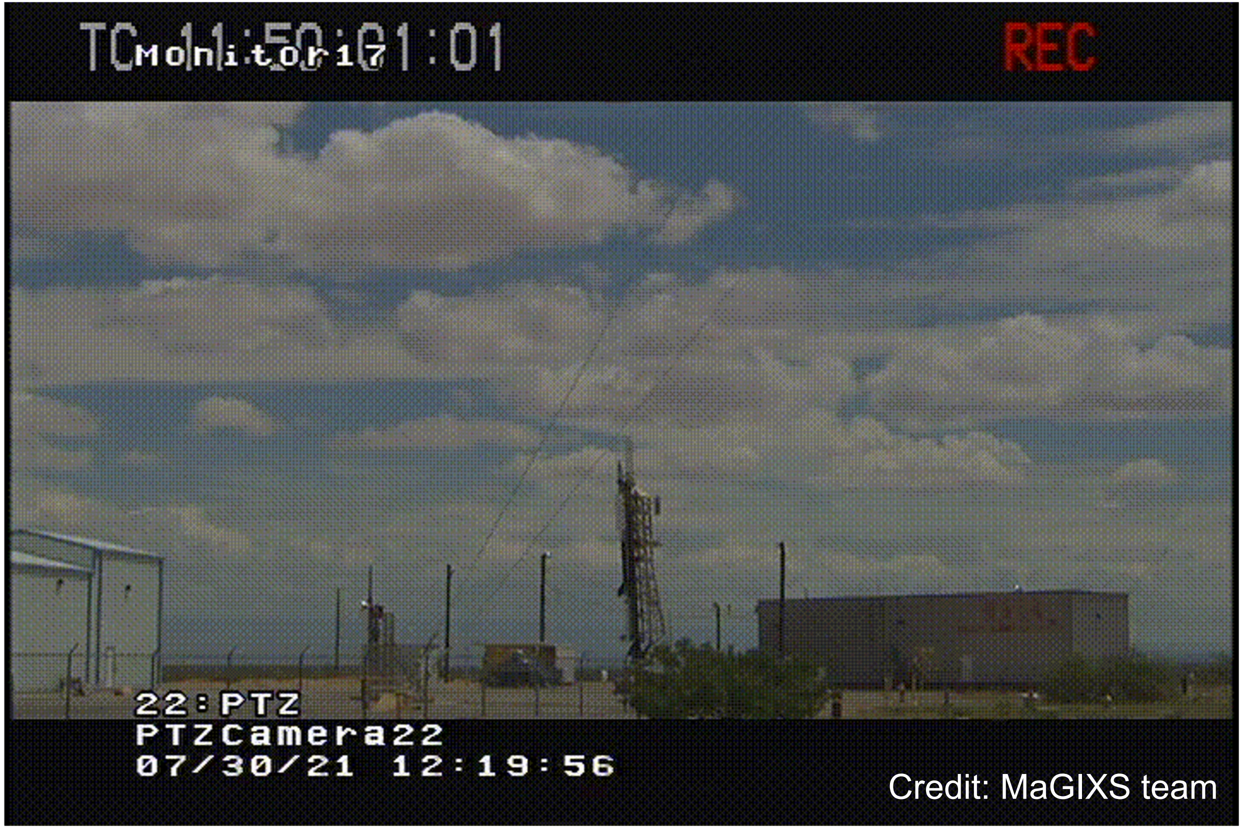
- Nanoflare can maintained the heating of XBPs (average temperature of 2MK).

- Nanoflares delay time is in the range of 1500 s to 3000 s.

- The average poynting flux of XBPs are found to be around 5×10^5 erg cm^{-2} s^{-1}.

- MaGIXS and XRT are more sensitive to diagnose the heating frequency, whereas only AIA channels are less sensitive.

MaGIXS-2 (This year)



Credit: MaGIXS team

Thank You for your attention!